Debris slides of Varandh Ghat, west coast of India

R. Nagarajan · M. V. Khire

Abstract On 28 June 1994 when 240 mm of rainfall occurred, a huge debris slide took place at Parmachi village in the Varandh Ghat of the Konkan district on the west coast of India. The debris slide resulted in extensive damage to property and killed 20 people in addition to numerous animals. The slide is considered to have occurred due to the development of hydrostatic pressure at the base of colluvial material, such that slope failure took place at the rock/soil interface. In view of the significance of such slides to settlements and highways, it is proposed that a warning system is developed based on a rainfall threshold of 170 mm in a 24-hour period.

Résumé Le 28 juin 1994 après une chute de pluie de 240 mm, un énorme glissement d'eboulis dans le village de Parmachi sur la côte occidentale de l'Inde (Varandh Ghat, district de Konkan). Le glissement a provoqué des dégâts considérables et tué 20 personnes. Il a été provoqué par une augmentation de la pression hydrostatique à la base des colluvions, la rupture se produisant à l'interface roche en place/éboulis. Compte tenu de l'importance de tels glissements sur l'habitat et les routes, la mise en place d'un système d'alarme, basé sur un seuil de 170 mm de précipitations en 24 heures, est proposé par les auteurs.

Key words Debris slide · Colluvium · Monsoon · Landslide · India

Introduction

During the monsoon period between June and September the occurrence of landslides and rock falls along road sections and natural slope facets is widespread in the Konkan district on the west coast of India. These slides hinder the movement of vehicular traffic on the roads connecting the coast to the hinterland. The volume of debris removed from the individual slides ranges from 1000 to 5000 m^3.
On 28 June 1994 a huge debris slide took place in the foothills of the Varandh Ghat (18°8′N; 73°36′E). This slide affected the village of Parmachi and for the first time in Konkan, involved fatalities with some twenty people killed as well as a number of animals. Three smaller slides were reported in nearby road sections of the mountain (ghat) on the same day.
It appears that there has been an increase in the occurrence of such slides in the recent past. This is causing particular concern as there are a number of settlements and industrial developments in the valley. This paper reports the work undertaken to assess the mechanism of the slides and determine the susceptibility of other slope facets to landslip movement. It provides an account of the debris slides of the Varandh Ghat region and discusses the geology, geomorphology and rainfall of the area in order to identify the likely causes and establish a landslide warning system.

Study area

The narrow Konkan coastal belt is located between the western ghat (also known as Shayadri) and the Arabian Sea and extends from Bombay to Goa (Fig. 1). Part of the western mountain range, the Varandh Ghat is situated 20 km east of Mahad, approximately 200 km south of Bombay and 90 km from Pune. A major arterial road passes through this region connecting the coastal area of Mahad with Pune in the hinterland. There are settlements on either side of this road as well as in the mid-slope area of the mountain.

Geology

Varandh Ghat and the adjoining areas form part of the western Deccan plateau of Cretaceous age (some 67 million years BP). The rocks are massive, fine grained, vesicular or amygdaloidal basalt. The tops of the individual near-horizontal lava flows are marked by the development of weathered horizons of red and green compacted clay known as

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R Nagarajan (✉) · M V Khire
Centre of Studies in Resource Engineering,
Indian Institute of Technology, Bombay 400-076, India

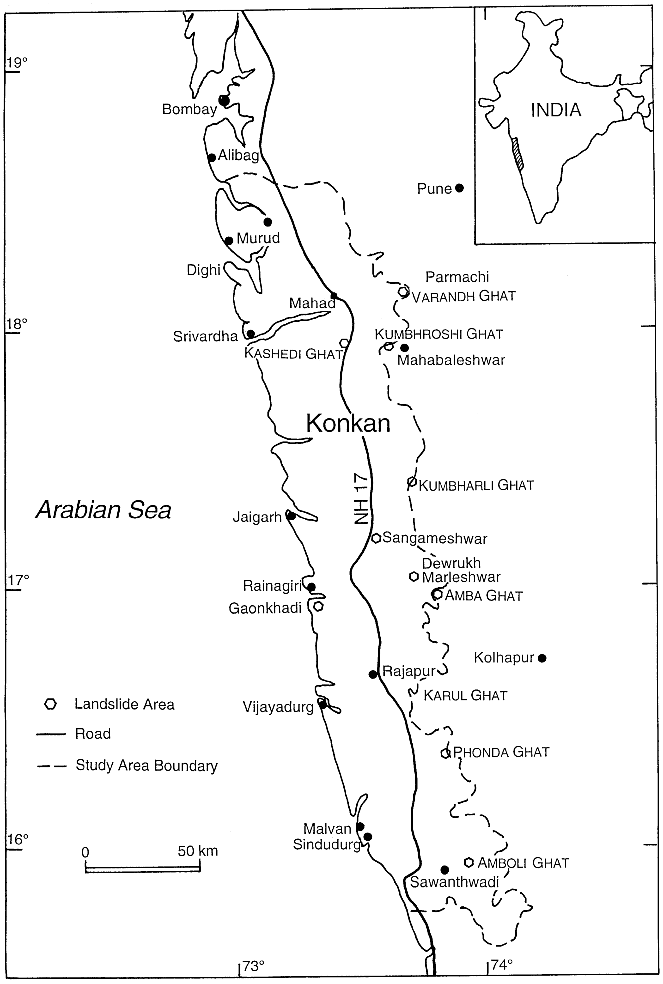

Fig. 1
Location of the Konkan on the west coast of India

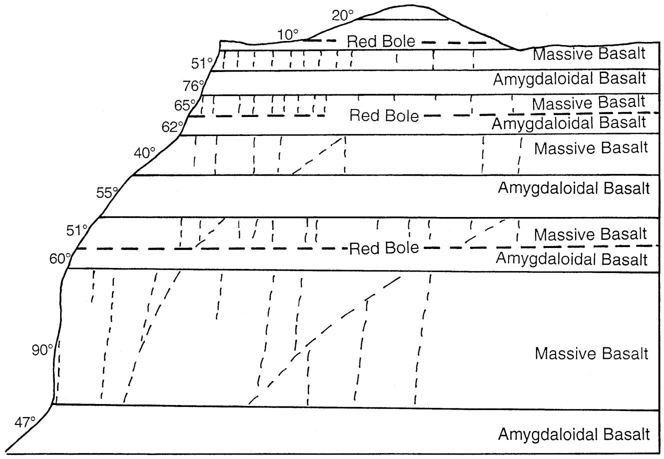

Fig. 2
Flow stratigraphy and slope profile of the western side of the Deccan plateau.

Red Bole. Spheroidal weathering of the rocks is observed below the soil cover, which in part has been aided by the development of joint sets within the volcanic material. As the vesicular/amygdaloidal lavas are more susceptible to weathering, the soil cover is generally thicker here than over the more massive lava flows.

A diagrammatic cross section showing the flow stratigraphy and slope profile is given in Fig. 2. As described by Nagarajan, Shah and Khire (1995), the main breaks of slope often occur where a prominent Red Bole layer outcrops.

Vertical, north-south and north-west/south-east trending discontinuities are observed in the lava flows in this area. The surfaces are frequently coated with quartz or calcite. These features are sufficiently prominent that the lineaments can be detected on the Indian remote sensing satellite imagery (Fig. 3). These data have been particularly valuable in showing the extent of the topographic features in this inhospitable, almost inaccessible area. Adjacent to the lineaments, the rocks are frequently fragmented such that they form major lines of water ingress and because of their steep nature, high water pressures may develop within these fractured zones. It is of note that some of the slides occur at the junction of these lineament features.

Lateritic duricrust is frequently exposed at the surface while where the rocks are more weathered, there is a dark reddish brown sandy loam with boulders. At the toe of the mountains, colluvial deposits are found consisting of poorly sorted, gap graded assemblages ranging from sand to clay with some boulders up to 2 m in size. However, the percentage of gravel, cobbles and boulders has not been accurately ascertained.

The top plateau region is barren except for a few shrubs. Vegetation growth on the 30–50° slope is moderate but again the steep slopes are devoid of any significant vegetation. Tree cutting to increase cultivation areas has been undertaken in some regions.

Rainfall

During the past twenty-five years the annual rainfall recorded at Mahad rain gauge station varied between 3 m and 5 m. The monsoonal rainfall in 1992 and 1994 is plotted as histograms in Figs. 4a and b respectively. The figures also indicate the dates of the main landslides in these years.

Landslides at Varandh Ghat

Numerous slides have been reported in the Ghat; their positions are shown in Fig. 3. The quantities of material disturbed by the numbered slides are given in Table 1. It can be seen that by far the largest of the landslides is that at Parmachi (1) which occurred on 28 June 1994 when over 110,000 m^3 of material was disturbed. The second largest slide (5) was at Ch 20 on 20 August 1992 and involved 16,000 m^3 of material.

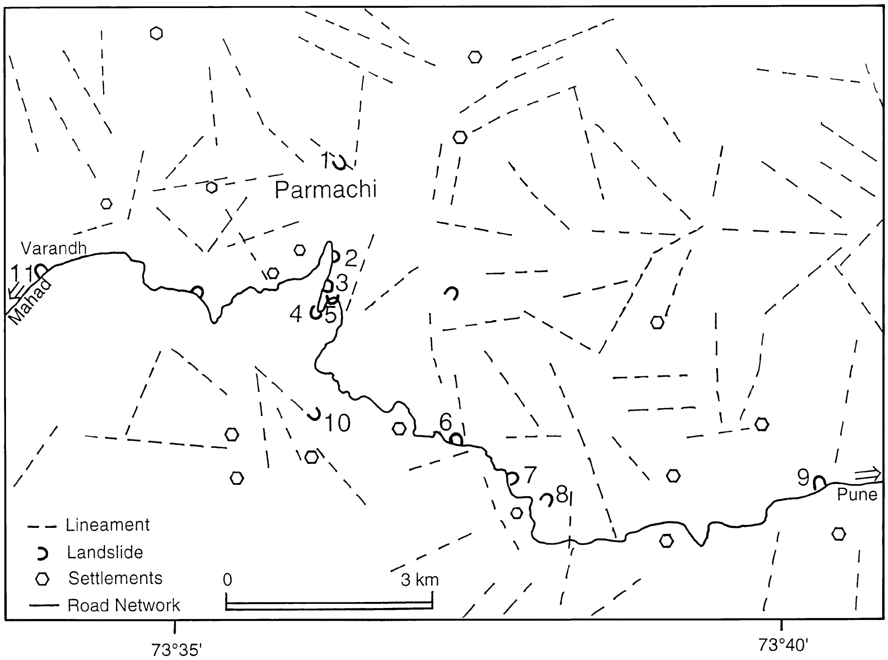

Fig. 3
Spatial distribution of landslides and lineaments in the Varndh Ghat

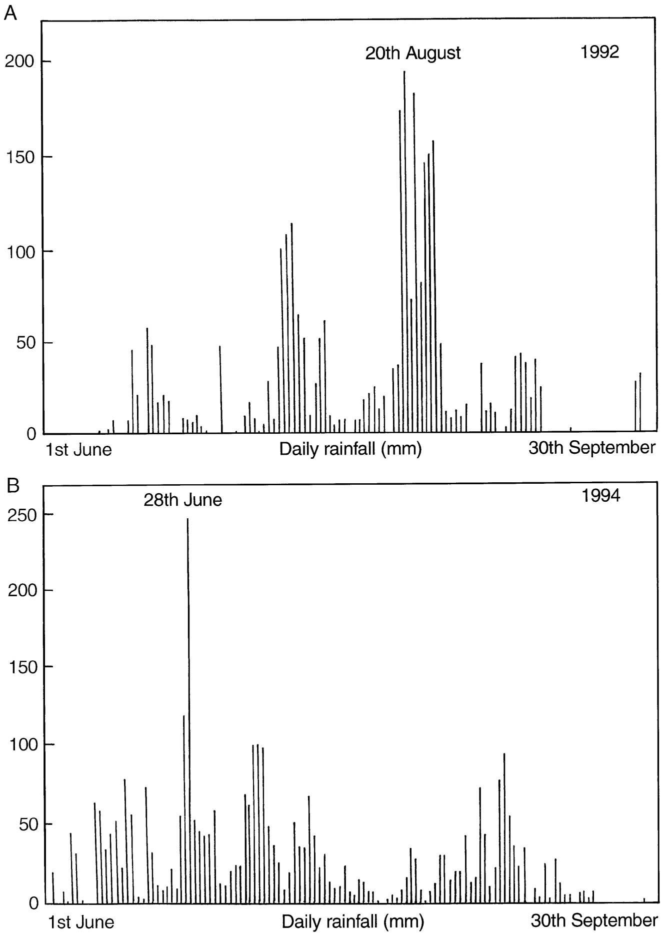

Fig. 4
A Total daily rainfall at Mahad during the monsoon of 1992; **B** Total daily rainfall at Mahad during the monsoon of 1994

Table 1
Dates of individual slides and the volume of material moved. The locations of the slides are shown in Fig. 3

Slide	Location	Date of Occurrence	Debris Volume (m^3)
1	Parmachi	28 June 1994	112 500
2	Ch 17	28 June 1994	5000
3	Ch 18	28 June 1994	10 000
4	Ch 19	28 June 1994	5000
5	Ch 20	20 August 1992	16 000
6	Ch 30	28 August 1992	3000
7	Ch 32	20 August 1992	1000
8	Ch 33	20 August 1992	1000
9	Ch 36	20 August 1992	500
10	Ch 38	28 June 1994	5000

Debris slide at Parmachi

On 28 June 1994 at about 1930 h a huge debris avalanche (as defined by Varnes 1978) took place on the toe of the mountain at Parmachi village (Fig. 5). The dimensions of the main slide were 300 m × 5 m × 70 m. A part of the colluvial deposit, on which irrigation water is used to aid cultivation, moved along the soil/rock interface from a height of 70 m, in an area where the gradient was almost vertical (80°). On one side the rock surface was smooth and fresh while on the other it was spheroidally weathered. The failure was related to a lineament feature (see Fig. 3) where the debris became so saturated that it moved as a slurry for a distance of 500 m, killing both people and animals and damaging houses and properties. The largest boulders were found to have travelled some 30 m with smaller rocks

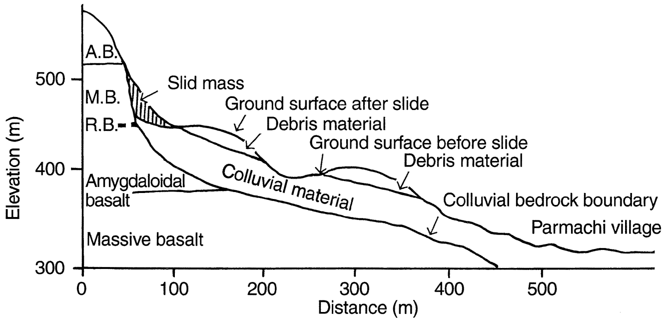

Fig. 5
Profile through the geology in which the Parmachi landslide took place

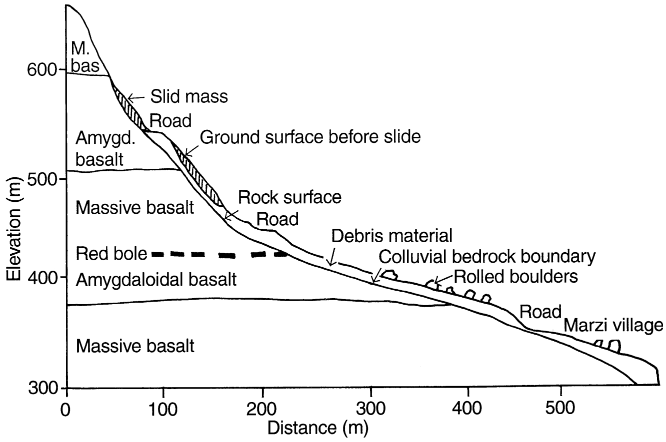

Fig. 7
Section of the slide at Chainage 20 km

moving about 150 m and cobbles and pebble sized material even further. A three-dimensional model showing a perspective view of the hill at Parmachi and the location of the slide is given in Fig. 6.

Unfortunately, due to the very poor visibility at the time, the villagers did not notice the early indications of the landslide. However, they reported "the ground started oozing from the floor and then [we] heard a loud noise followed by water in a slurry state gushing into the houses". Seepage of water indicated the ground was saturated and that artesian conditions existed at least for a temporary period. It is of note that on only one occasion (28 June) had the rainfall exceeded 120 mm in a 24-hour period but 240 mm of rain was recorded on the day of the slide, taking the total antecedant rainfall in a three-day period to 420 mm.

Other slides

In addition to the slide at Parmachi, other slides took place adjacent to the road as seen on Fig. 3. The material again slipped on the rock/soil interface. At several locations the road was breached due to excess run-off from the slope, affecting the traffic for several weeks. Similar conditions have existed for a number of years, hence it is necessary to develop a warning system such that villagers in downslope settlements can be alerted to the possibility of a landslide event, as well as those travelling along the highway.

On 20 August 1992 a debris slide took place at Ch 20 on the road section connecting Mahad and Pune (5, Fig. 3). The 80 m × 4 m × 50 m slide included highly weathered rock and boulders of volcanic breccia which moved down the steep slope for a distance of approximately 200 m. At this location the thickness of the soil talus is about 5 m while the road cut slope is at approximately 80°. A debris boulder 2 m × 1.5 m × 1 m in size rolled down the slope and came to rest only some 10 m outside of a settlement. Another boulder, 5 m × 3 m × 2 m in size, came to rest "hanging" on the edge of the road. Figure 7 shows a section line through the hill slope where the road zigzags across the mountain terrain. This slide is located just downslope of a heavily fractured rock (see Fig. 3). Again this debris slide occurred after a period of intense rainfall; 170 mm falling on 17, 18 and 20 August 1992 (see Fig. 4a).

On 28 June 1994, another slide took place in the mid-slope just below the 1992 slide. Both slides are close to a lineament and hence it is considered likely that the failures occurred when water pressures accumulated behind the talus slope during periods of heavy rainfall.

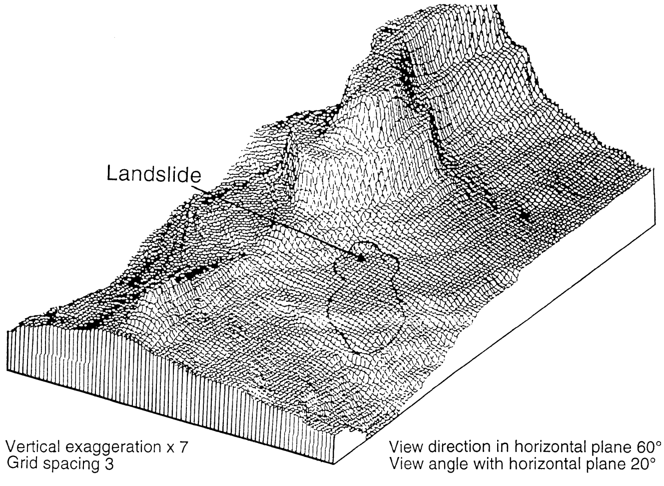

Fig. 6
Perspective view of Parmachi slide on digital elevation model

Geotechnical properties

Representative soil samples were taken from the sites of these slides. Cobbles and boulders were not collected but the particle size analyses carried out indicated 28–44% gravel, 36–50% sand and 12–28% fine fraction.

Discussion and conclusions

The area in which the landslides took place consists of almost horizontally bedded basalts which generally have a high resistance to weathering. However, the volcanic breccia, tuff and Red Boles are susceptible to weathering and hence these dominate the landforms and natural slopes in the area. Steep slopes are formed where compact basalt occurs while on the moderate and gentle slopes, colluvial deposits of between 5–10 m in thickness have accumulated. The high density of some of this colluvial material (2.34–2.58 g/cc) is likely to be related to post-depositional cementation. The permeability of the material is very high (Murray and Olsen 1990).

Reference to the time at which the main landslides took place and the rainfall data indicates that the debris slides/avalanches occur when the rainfall is continuous and exceeds 170 mm/day in the Varandh Ghat. The intense rainfall not only increases the surface flow but also induces a high piezometric head in the unsorted colluvium. The stability of the very wet surface material is further reduced along the lineament features where hydrostatic pressures on the unconsolidated material trigger downslope movement at the rock/soil interface. The poor sorting of the material is one of the factors favouring debris flow movement (Rodine and Johnson 1976). In addition, the clearance of natural vegetation and the development of agricultural practices prior to the monsoon facilitates ground water infiltration.

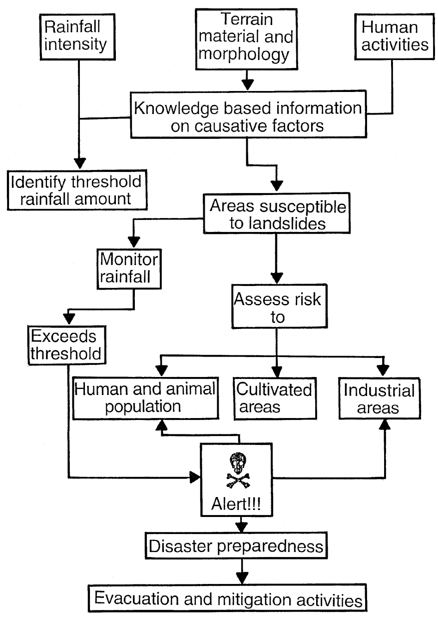

Fig. 8
Landslide hazard mitigation approach for high rainfall regions

The high pore pressures which develop in the near surface materials cause an area of the slope to move by gravity as a single mass. When this reaches the bottom of the valley the mass disintegrates into its individual soil particles, with the boulders advancing most rapidly. This depositional scenario compares with that described by Ikeya (1989).

A warning system has been developed based on the rainfall threshold index proposed by Malone (1988) to allow evacuation of villages and highways prior to a landslide event (Fig. 8). It is recommended that in the Varandh Ghat on the western side of the Deccan plateau, a warning should be issued as soon as the rainfall exceeds 175 mm in a 24-hour period. Traffic should be stopped or restricted and motorists alerted to the danger. It is also considered essential to undertake further research into the influence of rainfall on the colluvial deposits which exist on the steep slopes of this mountain range.

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